The Transition from "Normal" to "Broad Absorption Line Quasar" of Ton 34

Krongold, Y.[1]; Binette, L.[1]; Hernández-Ibarra, F.[1]

ABSTRACT

We report the emergence of a high velocity, broad absorption line outflow in the luminous quasar Ton 34, at z_q=1.928. The outflow is detected through an ultraviolet CIV broad absorption line, in a spectrum obtained in January 2006 by the Sloan Digital Sky Survey. No absorption trough was present in two different spectra acquired in 1981 at Las Campanas and Palomar observatories, indicating the emergence of the outflow in less than ∼8 yr (rest-frame). The absorption line spans a velocity range from ∼5,000-25,000 km s^{-1}, and resembles typical troughs found in Broad Absorption Line quasars (BALQSOs). We measure a balnicity index $\gtrsim$ 600 (though this value might be an underestimation due to a conservative placing of the continuum). The absorption trough is likely saturated, with the absorbing gas covering ∼25% of the emitting region. We explore different scenarios for the emergence of this outflow, and find an existing wind moving across our line of sight to the source as the most likely explanation. This indicates that high velocity outflows (producing broad absorption troughs in BALQSOs) might be ubiquitous in quasars, yet only become observable when the wind accidentally crosses our line vision to the central source.

Subject headings: quasars: absorption lines — quasars: individual (Ton 34)

1. Introduction

More than 50% of active galaxies and quasars display clear signatures of outflows, easily identified in the form of absorption lines (e.g. Crenshaw et al. 2003; Ganguly & Brotherton 2008). These lines appear in active galactic nuclei (AGN) spectra in different forms, either as broad absorption lines (BALs; FWHM∼10,000 km s^{-1}), narrow absorption lines (NALs; FWHM ∼100 km s^{-1}) and intermediate mini-BALs.

---

[1]Instituto de Astronomia, Universidad Nacional Autonoma de Mexico, Apartado Postal 70-264, 04510 Mexico DF, Mexico.

Understanding these winds is essential to understand the structure and dynamics of quasars (Elvis 2000). Since they carry mass and kinetic energy outside the central region of the host galaxy, it has been suggested that they may also be essential for galaxy evolution, being responsible for the relation between the mass of the supermassive black hole in the center of galaxies and their bulge velocity dispersion (Scannapieco and Oh 2004, Hopkins 2005, King 2010, Ostriker et al. 2010). They may also pollute with metals and heat the intergalactic medium, stopping structure formation. However, before these outflows can be used as cosmic probes, it is imperative to understand their nature. Unfortunately, there is little understanding so far on their origin, geometry and physical properties. In addition, we still do not know the relation among the systems with different FWHMs in their absorption lines, the exact relation between the UV and X-ray absorbers, and any possible connection between the absorbing and emitting gas in the central regions of AGN.

It has been suggested that the different UV and X-ray absorption lines with different FWHMs correspond to a single phenomenon, viewed at different angles, and that the same gas may be responsible for absorption and emission (e.g. Elvis 2000, Krongold et al. 2007, Andrade-Velazquez et al. 2010). Other ideas suggest that mini-BALs and BALs may represent the same outflow but at different evolutionary stages (Hamann & Sabra 2004). These ideas are not opposed to each other, as they describe different parts of the global picture.

Given that absorption lines provide information on the material located only in our line of sight to the source, and that the presence of outflowing material is not always evident in emission lines, one must rely on a different diagnostic to understand the true nature of these winds. Line variability has proven to be an effective method to study AGN winds. However, the variations can be produced by different effects, such as changing in the ionization state of the gas, changes in column density, or changes in covering factor, and these effects are not always straightforward to differentiate. Line variations in BALQSOs are generally small, indicating that BAL winds are long-lived stable flows (Barlow 1994; Lundgren et al 2007; Gibson et al. 2008). However, in two cases, strong variations have been found, showing the emergence of BAL (or BAL-like) outflows. Leighly et al. (2009) reported the appearance of BAL troughs in the Narrow-Line Seyfert 1 galaxy WVPS 007, an object where a BAL outflow is not expected given its intrinsic low luminosity. Hamann et al. (2008) reported the appearance of broad absorption lines in the spectra of quasar J105400.40+034801.2. The lines, though typical of BALQSOs, presented a velocity shift of 26,300 km s^{-1}, which resulted in a balnicity index of zero[1], excluding them from the standard BAL definition (Weymann

---

[1]The balnicity index (which is to be applied to C IV) measures the equivalent width of strong absorption features (expressed in km s^{-1}), but requires that each absorption feature contributing to the index spans at least 2000 km s^{-1} (to exclude intervening systems) and only includes in the calculation absorption regions

et al. 1991).

In this paper we report the emergence of a BAL outflow in the luminous quasar Ton 34 (PG 1017+280). Ton 34, at $z_q = 1.928$, represents an extreme case of the continuum decline (or UV-break) that takes place in quasar spectra shortward of ≈ 1100 Å (Telfer et al. 2002, hereafter TZ02), contrasted by a "normal" spectrum redward of this break. If the far UV decline is fitted by a powerlaw ($F_\nu \propto \nu^{+\alpha}$), the index value in Ton 34 is $\alpha = -5.3$, remarkably steeper than the 'average' spectral energy distribution (SED) derived by TZ02, which behaves as $\nu^{-1.76}$ (in fact, among the 77 far UV indices measured by TZ02, only in 3 objects there was an ionizing continuum steeper than ν^{-3}). Binette & Krongold (2008a) suggested that the extreme UV flux might undergo a recovery shortward of 450 Å (as hinted by IUE data), and studied the possibility that the particular shape of the SED could be the result of carbon crystalline dust absorption (Binette et al. 2005, Haro-Corzo et al. 2007). They found that moderate columns of dust could indeed reproduce the UV-break. However, due to the observational limits on atomic gas absorption, they hypothesized the possibility that the dust was part of an ionized high-velocity flow in this system. Given the lack of UV ionizing photons in the SED of Ton 34, Binette & Krongold (2008b) further analyzed the emission line spectrum of this quasar. They find evidence of an unusual strength (relative to Lyα) of low to intermediate excitation lines (such as OII + OIII $\lambda\lambda$835, NIII + OIII $\lambda\lambda 686 - 703$, and NIII + NIV $\lambda\lambda$765), which could not be explained by photoionization processes in the emitting gas, but rather by shock excitation.

2. Multi-time Spectra of the Quasar TON 34

The Sloan Digital Sky Survey (SDSS) carried spectroscopic observations of the quasar Ton 34 on January 30, 2006. The fully reduced spectrum was retrieved from the SDSS data release 7 (Abazajian et al. 2009). The spectrum covers the spectral range between 3808 and 9215 Å (1335 to 3147 Å in the rest frame of Ton 34), with a resolving power ∼2000 (130 km s^{-1}). According to the SDSS data release, an uncertainty of less than 3% is expected in the flux calibration. The S/N ratio ranges from 45 in the blue end to 39 in the red one. A detailed analysis of the full range spectrum will be presented in a forth coming paper (Binette et al. in preparation).

To study the spectral variability in Ton 34, we refer to the published optical spectrum

---

dipping 10% or more below the normalized continuum. In addition, the first 3000 km s^{-1} blueward of the emission peak are excluded to distinguish "associated absorption" from broad absorption. For further details see Appendix A in Weymann et al. (1991).

obtained by Sargent et al. (1988). Only for illustrative purposes, we present here the digitized data presented by Binette & Krongold (2008a,b). Briefly, we describe the properties of the data, as reported by Sargent et al. (1988). The spectrum was taken at the Palomar 5.08m Hale Telescope (we focus on the red arm spectrum, covering the C IV region of interest), between November 19-21, 1981. The total exposure time was 13,500 s. The resulting spectrum covers the spectral range between 3600 and 4810 Å (1229 to 1642 Å in the rest frame of Ton 34) with a resolution $\sim$100 km s^{-1}. The S/N ratio is $\sim$75 in the region between the Lyα and C IV emission lines. The data was acquired with the sole purpose of detecting broad and narrow absorption lines, and thus, only a relative flux calibration was carried out.

The spectra was corrected for Galactic reddening assuming the Cardelli et al. (1989) extinction curve corresponding to R_V=3.1 and E_{B-V}=0.13. The latter value corresponds to the mean extinction inferred from the 100μ maps of Schlegel et al (1998) near Ton 34. We note however, that this correction has no effect on the results presented here. Throughout this paper we assume a cosmology consisting of H_o=71 km s^{-1} Mpc^{-1}, $\Omega_M = 0.27$, and $\Omega_\lambda = 0.73$.

3. The Emergence of a BAL Flow

Figure 1 presents the full band SDSS rest-frame spectrum of Ton 34. A visual inspection hints at the presence of a strong broad absorption line blueward of the CIVλ1549 emission line region. However, given the numerous emission features present in the region covered by the spectrum redward of this emission line (including strong blends of Fe II transitions), a full band continuum determination is not straightforward (for a detailed analysis of the full band spectrum see Binette et al., in preparation). Since our goal is to test the presence of a CIV BAL trough, we defined the most conservative continuum level, as shown in Figure 1. To define this continuum, we fit a simple powerlaw to the “line free regions” in the full band spectrum, particularly, we forced this simple powerlaw to fit the regions around 3000-3100 Å (assumed to be a “good continuum representation” given the lack of Fe II emission) and the line free regions between 1320 and 1380 Å (so that in the continuum determination we are assuming no absorption by Si IV). This simple fit also provides a good continuum description of the two line free regions close to 1600 Å and 1700 Å. We note that other representations of the continuum (including local fits to the CIV- SiIV region or broken power laws) are possible, though all of them would place the continuum at higher flux levels, making the absorption trough stronger. The emission lines in the blue part of the spectrum were fit using up to two different Gaussian components. These lines are reported in Table 1.

Figure 2 presents the same fit on the 1300-1600 Å spectral region, along with the normalized spectra (in velocity space). The spectral fit to the SDSS spectrum clearly shows the presence of a strong broad absorption line consistent with absorption by CIVλ1549 with velocities ranging from $\sim$5,000-25,000 km s^{-1} with respect to the rest frame of the source. This feature was not present during the Palomar observation $\approx$24.2 years before ($\approx$8.3 years in the rest frame). We note, however, that other narrow absorption features present in the Palomar spectrum (probably intervening systems from the inter-galactic medium) are also present in the SDSS spectrum. It should be stressed that the Palomar data was obtained with the sole purpose of discovering absorption lines (both narrow and broad) in the spectrum of Ton 34. Yet, no BAL line was reported by Sargent et al (1988). Additional confirmation of the lack of the BAL comes from a former spectrum taken at Las Campanas (100 inch telescope) in March 11, 1981 (Young et al. 1982), obtained also with the sole purpose of detecting absorption lines.

To further illustrate the emergence of the BAL, we present in Figure 2 the earlier Palomar spectrum, digitized. This plot also shows the Palomar normalized spectrum, after performing a continuum plus emission line fit, similar to the one applied to the SDSS data.

4. Discussion

The absorption feature present in the SDSS spectrum of Ton 34 resembles typical CIV troughs found in BALQSOs. This feature spans velocities ranging from $\sim$5,000-25,000 km s^{-1}, with a FWHM$\sim$ 9,000 km s^{-1}. Following the standard BAL definition (Weymann et al., 1991), we calculate a balnicity index $\gtrsim 600$, but note that this index strongly depends on the continuum determination, thus, it could easily be much larger. Given our continuum determination, no absorption by SiIV was detected, although the possible presence of this line is strongly dependent on the actual continuum level. We note however, that SiIV absorption is not always observed in the spectra of BALQSOs.

The spectral shape of the absorption feature cannot be adjusted with two Gaussians, shifted by $\sim$ 300 km s^{-1} to account for the CIV$\lambda\lambda$1548,1550 doublet. Rather, a velocity structure is evident (suggesting a velocity dependent covering factor), with the absorption becoming more prominent between 18,000-20,000 km s^{-1}. We estimate the column density directly from the normalized data using equation (9) by Savage & Sembach (1991). We integrate the column density over the line profile assuming the 2:1 ratio in the oscillator strengths of the CIV doublet, i.e. we assume that the line is optically thin. Doing this we measure a CIV column density $> 2 \times 10^{15}$ cm^{-2}. However, we consider this a very uncertain lower limit given that the lines might be highly saturated and the covering fraction might

be much smaller than one. We have no means to measure the saturation level of the lines with the current data, however, saturation and partial covering have been observed in other UV outflows (e.g. Arav et al. 2001, Hamann & Sabra 2004, Gabel et al. 2005). If the line was indeed highly saturated (optical depth $\tau_o > 3$ in the center of the line), then the CIV column density would be larger than 10^{16} cm^{-2}, and from the residual flux in the core of the line the covering factor would be $\sim$25%.

Following Hamann et al. (2008) we can compare different time-scales relevant to the system to the timescale in which the outflow appeared in the spectrum of Ton 34 (<8.3 years, rest frame of the source), to test different processes responsible for the emergence of the flow. Assuming that the wind originates in the accretion disk, then a characteristic time-scale for the flow is simply $t_{wind} \sim R_{wind}/v_{wind}$, where R_{wind} is the distance from the wind to the central source, and v_{wind} the wind velocity. For accretion-disk winds R_{wind} is expected to lie just beyond the CIV emission line region (e.g. Everrett 2005, Proga 2007). Using equation (3) from Kaspi et al. (2007), and the 1350 Å luminosity of Ton 34, we estimate $R_{CIV} \sim 2 \times 10^{18}$ cm, which along with $v_{wind} \sim$19,000 km s^{-1} yields a flow timescale $t_{wind} \sim$33 yr. This is a factor $\gtrsim 4$ larger than the elapsed time between the observations, making the hypothesis of an arising flow unlikely.

On the other hand, the crossing time of absorbing clouds through the continuum source is generally smaller than the flow time. A typical crossing time-scale can be obtained from the ratio between the size of the emitting region and the transverse velocity of the clouds, $t_{cross} \sim R_{em}/v_{tr}$. Assuming v_{tr} is similar to the rotational speed in the BLR, we can estimate this quantity from the width of the CIV emission line, thus $v_{tr} \sim$2500 km s^{-1}. Since the size of the emitting region is constrained by the variability timescale of the source, from variability studies we can estimate R_{em}(1500 Å)$\sim few \times 10^{16}$ (e.g. Kaspi et al. 2007). Thus $t_{cross} \sim$4 yr, making the possibility that an existing flow got into our line of sight consistent with the observations.

We further consider the hypothesis that changes in ionization state may have produced the appearance of the absorption line. We only consider the possibility of a decrease in ionization as no broad absorption by HI was observed in the Palomar spectra (Sargent et al. 1988). Thus, if the wind was already present during the earlier observation, its ionization level would have to be much larger than during the SDSS one. We do not have accurate physical properties (i.e. ionization parameter and temperature) of the absorbing gas to calculate the photoionization equilibrium time-scale (e.g. Krongold et al. 2005, 2007). However, we can calculate the recombination time (defined as the inverse of the recombination coefficient times the electron density of the gas) for CV, which is an upper limit to this time-scale (Nicastro et al. 1999). We draw the recombination coefficient from

Shull and Van Steenberg (1982) and assume a temperature of $few \times 10^4$ K. In order for the gas to recombine and the trough to emerge in the spectrum of Ton 34 in the 8.3 yr interval between the observations, the number density of the absorber need to be > 100 cm^{-3}. Thus, the possibility of a decrease in ionization state is also consistent with the observations. Nevertheless, we consider this alternate possibility less likely, given that a large change in the ionizing flux would be required to produce such a large change in the ionization state of the gas, which is not typically observed in quasars. On the other hand, the unusual SED of Ton 34 and the lack of recent extreme UV observations prevents us from ruling out this idea.

Finally, we stress that the extreme far UV break observed in the spectrum of Ton 34 is difficult to explain in terms of accretion disk models. This break can be explained (see review by Binette et al., 2008c) in terms of atomic absorption by an ionized, nearly relativistic outflow (Eastman et al. 1983), or in terms of absorption by an intervening carbon crystalline dust component close to the quasar. In the case of Ton 34, Binette & Krongold (2008a) concluded that the dust component should be part of an ionized medium, and hypothesized that it could be part of a (moderate velocity) outflow. If the emission line region is located closer to the ionization source than this outflow, this would also bring the required SED by photoionization models to a much better agreement with the intrinsic SED of the central source. In the case of three AGN, namely quasar Ton 34, NLSy1 galaxy WVPS 007 (Leighly et al. 2009), and quasar J105400.40+034801.2 (Hamann et al. 2008), the emergence of a BAL outflow has been reported. For the two quasars the most likely explanation is that the outflow was already present and simply intersected our line of sight (also possible for WVPS 007). This may imply that such outflows are ubiquitous in quasars, yet only become observable when the absorbing material accidentally crosses our line vision to the central source. In the case of Ton 34, a subject that deserves further attention is the fact that an outflow emerged in a quasar with such an extreme SED.

We thank the anonymous referee for constructive comments that helped to improve the paper. This work was supported by the UNAM PAPIIT grant IN104009. The results presented in this paper include observations from the SDSS facilities (obtained from the data archive at the web site http://www.sdss.org/).

REFERENCES

Abazajian, K. N., et al. 2009, ApJS, 182, 543

Andrade-Velázquez, M., Krongold, Y., Elvis, M., Nicastro, F., Brickhouse, N., Binette, L., Mathur, S., & Jiménez-Bailón, E. 2010, ApJ, 711, 888

Arav, N., et al. 2001, ApJ, 561, 118

Barlow, T. A. 1994, PASP, 106, 548

Binette, L., Magris C., G., Krongold, Y., Morisset, C., Haro-Corzo, S., de Diego, J. A., Mutschke, H., & Andersen, A. C. 2005, ApJ, 631, 661

Binette, L., & Krongold, Y. 2008a, A&A, 478, 739

Binette, L., & Krongold, Y. 2008b, A&A, 477, 413

Binette, L., Haro-Corzo, S., Krongold, Y., & Andersen, A. C. 2008c, Revista Mexicana de Astronomia y Astrofisica Conference Series, 32, 115

Cardelli, J. A., Clayton, G. C., & Mathis, J. S. 1989, ApJ, 345, 245

Crenshaw, D. M., Kraemer, S. B., & George, I. M. 2003, ARA&A, 41, 117

Eastman, R. G., MacAlpine, G. M., & Richstone, D. O. 1983, ApJ, 275, 53

Elvis, M. 2000, ApJ, 545, 63

Everett, J. E. 2005, ApJ, 631, 689

Gabel, J. R., et al. 2005, ApJ, 623, 85

Ganguly, R., & Brotherton, M. S. 2008, ApJ, 672, 102

Gibson, R. R., Brandt, W. N., Schneider, D. P., & Gallagher, S. C. 2008, ApJ, 675, 985

Hamann, F., & Sabra, B. 2004, AGN Physics with the Sloan Digital Sky Survey, 311, 203

Hamann, F., Kaplan, K. F., Rodríguez Hidalgo, P., Prochaska, J. X., & Herbert-Fort, S. 2008, MNRAS, 391, L39

Haro-Corzo, S. A. R., Binette, L., Krongold, Y., Benitez, E., Humphrey, A., Nicastro, F., & Rodríguez-Martínez, M. 2007, ApJ, 662, 145

Hopkins, P. F., Hernquist, L., Cox, T. J., Di Matteo, T., Martini, P., Robertson, B., & Springel, V. 2005, ApJ, 630, 705

Kaspi, S., Brandt, W. N., Maoz, D., Netzer, H., Schneider, D. P., & Shemmer, O. 2007, ApJ, 659, 997

King, A. R. 2010, MNRAS, 402, 1516

Krongold, Y., Nicastro, F., Brickhouse, N. S., Elvis, M., & Mathur, S. 2005, ApJ, 622, 842

Krongold, Y., Nicastro, F., Elvis, M., Brickhouse, N., Binette, L., Mathur, S., & Jiménez-Bailón, E. 2007, ApJ, 659, 1022

Leighly, K. M., Hamann, F., Casebeer, D. A., & Grupe, D. 2009, ApJ, 701, 176

Lundgren, B. F., Wilhite, B. C., Brunner, R. J., Hall, P. B., Schneider, D. P., York, D. G., Vanden Berk, D. E., & Brinkmann, J. 2007, ApJ, 656, 73

Nicastro, F., Fiore, F., & Matt, G. 1999, ApJ, 517, 108

Ostriker, J. P., Choi, E., Ciotti, L., Novak, G. S., & Proga, D. 2010, arXiv:1004.2923

Proga, D. 2007, ApJ, 661, 693

Sargent, W. L. W., Boksenberg, A., & Steidel, C. C. 1988, ApJS, 68, 539

Savage, B. D., & Sembach, K. R. 1991, ApJ, 379, 245

Scannapieco, E., & Oh, S. P. 2004, ApJ, 608, 62

Schlegel, D. J., Finkbeiner, D. P., & Davis, M. 1998, ApJ, 500, 525

Shull, J. M. & van Steenberg, M. 1982, ApJS, 48, 95

Telfer, R. C., Zheng, W., Kriss, G. A., & Davidsen, A. F. 2002, ApJ, 565, 773

Weymann, R. J., Morris, S. L., Foltz, C. B., & Hewett, P. C. 1991, ApJ, 373, 23

Young, P., Sargent, W. L. W., & Boksenberg, A. 1982, ApJS, 48, 455

Table 1. Emission Lines in the SDSS data

Species	λ (Å)	FWHM (km s^{-1})	Flux (10^{-14} erg s^{-1} cm^{-2})
Broad Components			
C IV	1549	5600	16.0
Si IV	1402	3400	7.0
C II	1335	3300	2.8
O I	1302	5800	6.0
Narrow Components			
C IV	1549	1700	1.4
Si IV	1402	1900	2.9

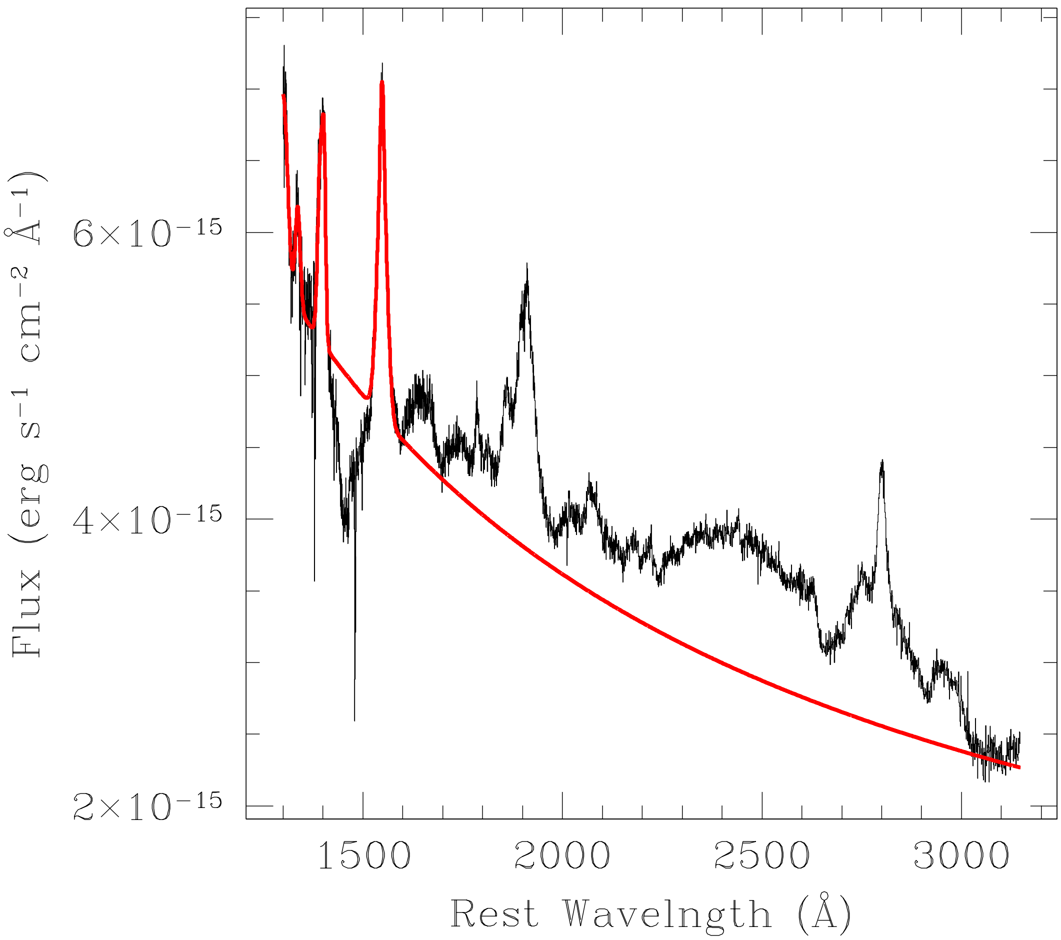

Fig. 1.— Full band rest-frame SDSS spectrum of quasar Ton 34. The red line corresponds to the continuum plus emission lines (in the blue part of the spectrum) adopted in this paper.

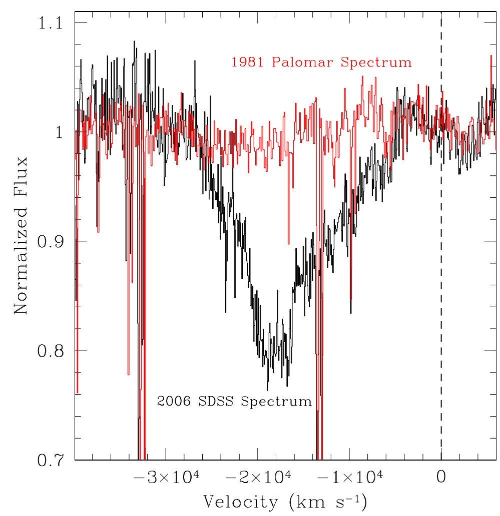

Fig. 2.— Left: 2006 SDSS spectrum of Ton 34 in the 1300-1600 Å range (rest-frame). The red line represents the (full range) continuum plus emission lines fit. For illustrative purposes, the 1981 Palomar digitized spectrum (Sargent et al. 1988) is also shown, along with the best continuum plus lines fit (blue line). The spectra is presented in arbitrary flux units. Right: Normalized SDSS and Palomar spectra in velocity space. The emergence of a CIV BAL is evident in the data.